Evolutionary Actor-Multi-Critic Model for VNF-FG Embedding

Yassine Hadjadj-Aoul, Pham Tran Anh Quang, Abdelkader Outtagarts

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Presenter

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Collaborative work

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Outline

- Introduction
- VNF-FG Placement problem
- State of the Art
- Motivations
- DRL Agent + Evolutionary Actor-Multi-Critic Model
- Results
- Conclusions

Idea behind networking slicing …

- Network slicing allows to simultaneously accommodate a wide range of services
  - over a common network infrastructure
- May support new services on-demand and in near real-time

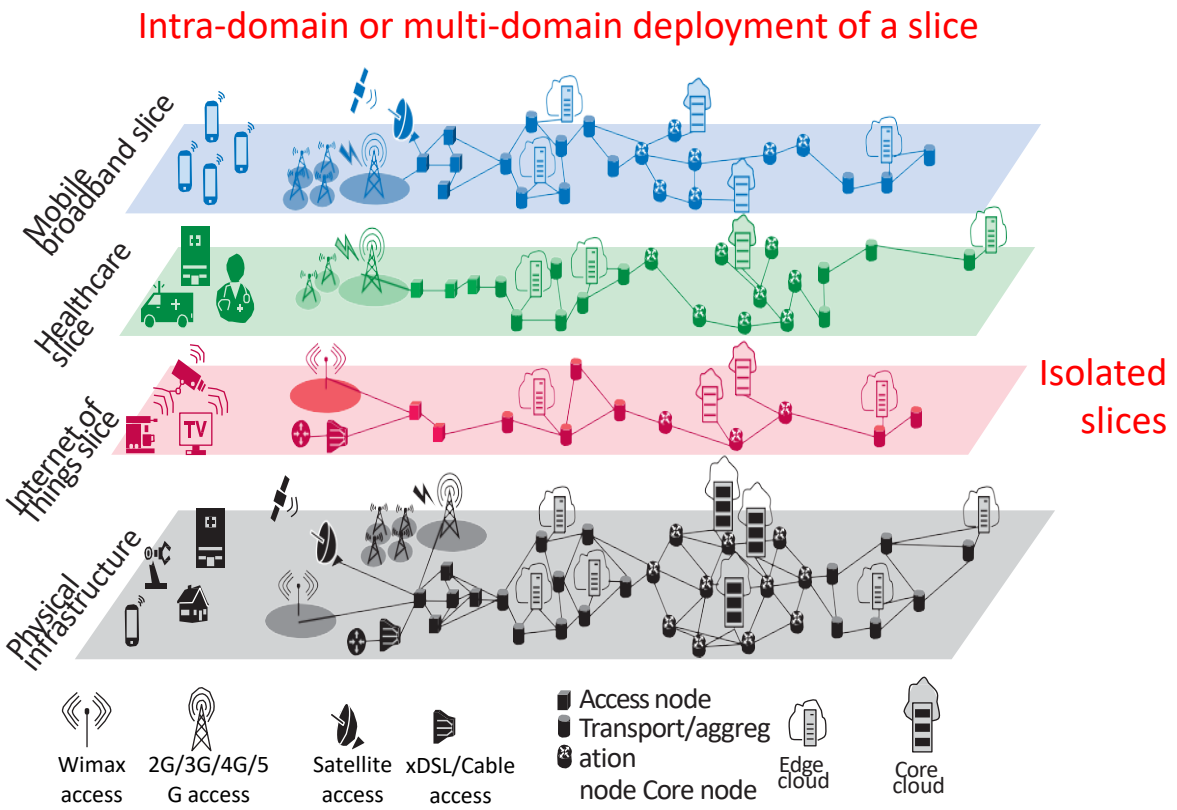


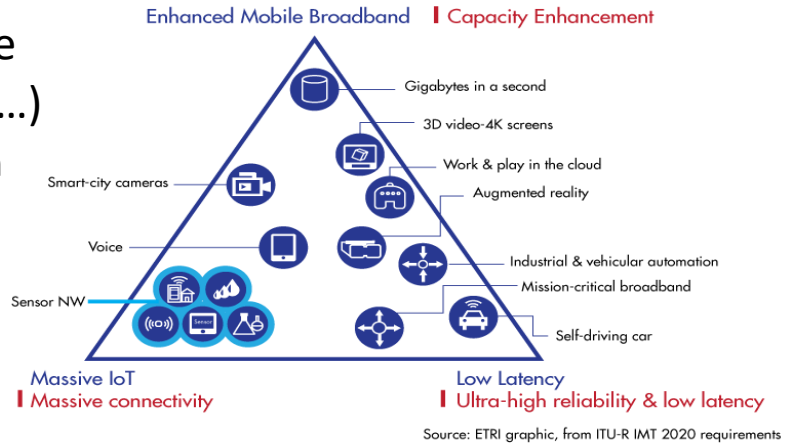
Figure taken from an IEEE ComMag paper

What are the challenges facing network operators today?

What are the challenges facing network operators today?

- Ever-increasing infrastructure complexity
  - Diversification of services (IoT, Smart cars, …)
    - Very diverse needs in terms of QoS (SLA)
    - Within the same network infrastructure
  - Limits of the human being to manage a large number of equipments (10K, 100K devices, …)
    - Very high risk of mistakes, the cost of which can be prohibitive
    - Very slow service provisioning (not automated)

Complex networks



Source: ETRI graphic, from ITU-R IMT 2020 requirements

What are the challenges facing network operators today?

High costs

- Very high investment (CAPEX) cost
  - Equipment excessively expensive to purchase
- Very high operational (OPEX) cost
  - Significant operational costs with the human factor at the different levels of control and supervision

What are the challenges facing network operators today?

- Lack of agility
  - Equipment that can hardly be adapted to the needs and of which any update is complex and not always possible
  - Scaling is not always possible and oversizing is costly (unlike the Cloud)

What are the challenges facing network operators today?

- It is very difficult to grow
  - Renting infrastructure is no longer as profitable
    - Difficult to be profitable when you don't decide on the rates
    - It's difficult to get a return on investment when having a continuous evolution of the infrastructure …
  - Operators are not part of the delivery chain of the service, which is very profitable (e.g. CDN)

No growth

Operators' needs

- Automated network infrastructure
  - Self configuration, self healing, self scaling, self *, …
- Supporting current and future services within the same infrastructure
  - With very diverse constraints (latency, bandwidth, loss, CPU, FPGA, …)
- Softwarization of the network and the services
  - Ability to lease infrastructure to third parties without compromising the network and its efficiency
  - Higher programmability (e.g. Yang, P4 …)
- Being part of the service delivery value chain

Complex networks

High costs

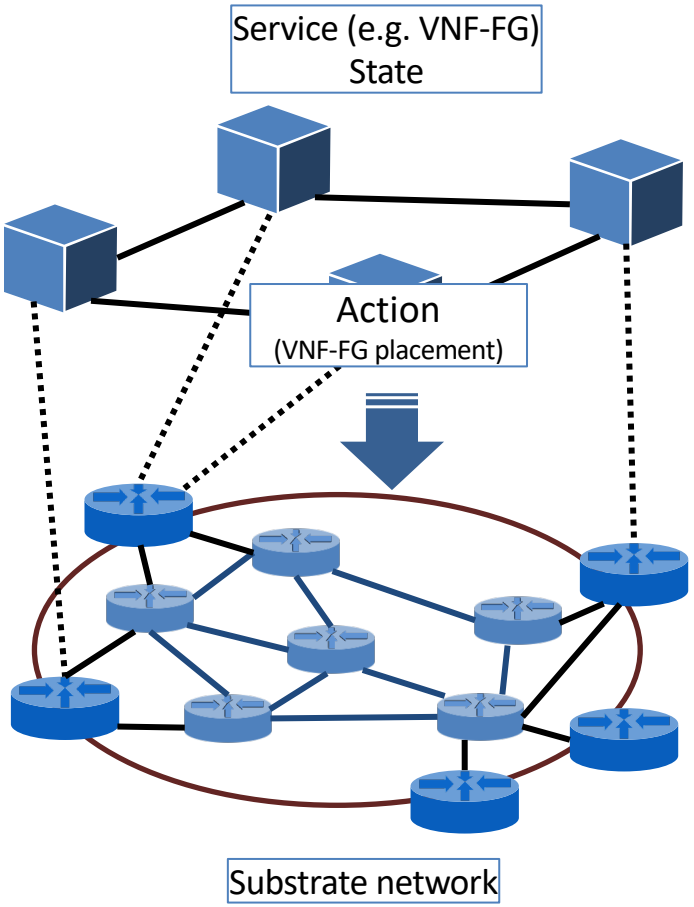
Lack of agility

No growth

Network slicing (in particular) is seen as an opportunity to meet these different objectives

In practice, what does slicing a network consist of?

- Most simple form
  - Placement of services consisting in one VNF
    - Offline vs online problem (bin packing problem)
      - May consider 1 or several metrics for the placement (e.g. latency, load, reliability, …)
    - NP-complete problem
- More advanced form (more complex)
  - Placement of services in a VNF-FG form
    - Involves not only the placement of VNFs but also addressing a routing problem
    - Need to consider several metrics (QoS requirements)
- Most advanced forms
  - Placement and scalability of services
  - Run-time placement
  - …



What metrics are considered for placement?

- This naturally depends on the problem being addressed (SLA) ...
  - Reliability
    - Loss
    - K-connectivity, average connectivity, …
  - Service requirements
    - Bandwidth
    - **System requirements (CPU, RAM, Disk, FPGA, …)**
    - **QoS**/QoE
    - Load balancing
  - Scalability
  - Energy/power saving

Some problems require addressing one metric and others several metrics at a same time ... with the risk of a combinatorial explosion.

Services placement: A well studied problem!

- The problem of placement is an old and well-studied problem[1]
  - Many papers in the Cloud context
  - Conventional service placement comes down to a problem of bin-packing or knap-sack
    - NP-hard problem
  - Realistic placement of services, like the VNF-FG placement is much more complex
    - Services are composite, since they include several sub-services, and multi-constrained
      - Must be added the multiple constraints on the links
- Less attention has been paid to the placement of VNF-FG, which is actually a fairly recent issue
  - Most of the paper address the problem of VNE, which is less complex

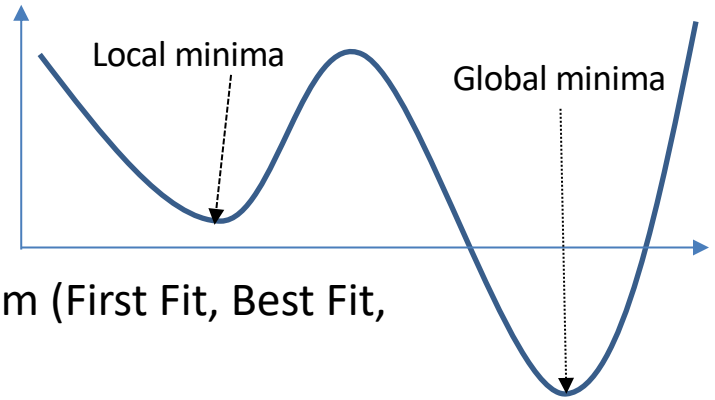
1 DANTZIG, G. B., "Discrete-Variable Extremum Problems", *Opns. Res. Soc. Am. 5*, 266-277 (1957)

Classification of existing Approaches for the Placement

1. Mathematical optimisation-based approaches
   - Most of the paper fall in this category
   - Use of: Integer Linear Program (ILP) or Mixed ILP (MILP) …
     - Integer Programming is an NP-complete problem. So:
       - There is no known polynomial-time algorithm
       - Even small problems may be hard to solve
         - » Propose more efficient heuristics for solving the problem, so they fall into another category.

- Main limitation:
  - **Some parameters are only obtained during run-time (latency and loss) which makes these approaches sometimes ineffective in a real context.**

Classification of existing Approaches for the Placement



2. Heuristics-based approaches
   - Most of the paper fall in this category
   - Use generally : a two step approach
     - Placing VNFs using traditional algorithm (First Fit, Best Fit, nearest search procedure, …)
     - Then placing VLs (using Shortest path ”SP”, K-SP, …)
     - Very fast, effective and deal with very large problems
       - » **For some industrials, this is the best solution**

- Main limitation:
  - In systems where **constraints and objectives are changing**, these types of approaches are **not very suitable** since they generally **require a total redesign**. Moreover, with heuristics we have a rapid convergence at the price of the risk of **sticking at a local minima**.

Classification of existing Approaches for the Placement

3. Metaheuristics-based approaches
   - Use generally : a two step approach
     - Placing VNFs using an evolutionary, greedy, … algorithm
     - Then placing VLs using Shortest path ”SP”, … or using a metaheuristic
     - Slow, very effective and deal with very large problems
       - » Explore all solutions, or only feasible solutions (faster with risk of stacking at a local optimum)
     - With enough time this may converges to global optimum
   - Comment …
     - As the fitness (cost) function is function of VNFs + VLs placement … **it comes to placing both at the same time …**

Pham Tran Anh Quang, Jean-Michel Sanner, Cédric Morin, and Yassine Hadjadj-Aoul : “Virtual Network Function Forwarding Graph Embedding: A genetic algorithm approach”. In Wiley, IJCS (August 2019)

Classification of existing Approaches for the Placement

3. Metaheuristics-based approaches
   - Features and main limitation:
     - Metaheuristics make it possible to respond effectively to the problem VNF-FG placement. They can very easily integrate new objectives or constraints without reconsidering the solution, unlike heuristics.
   - However, to address a new placement you almost always need to start from the beginning … as there is **no real learning**

Classification of existing Approaches for the Placement

4. Learning-based approaches
   - Only very few approaches (not so few now)
   - Use generally : a two step approach but … the reward function concerns VNFs + VLs placement, which means that we are addressing both at the same time.
     - Very slow
       - » Unclear whether these approaches can adequately address the problem.

- Main limitation:
  - Efficient approaches still need to be developed.

Pham Tran Anh Quang, Yassine Hadjadj-Aoul, and Abdelkader Outtagarts : “A deep reinforcement learning approach for VNF Forwarding Graph Embedding”. In IEEE TNSM (October 2019)

Deep Learning Approach

- Machine Learning or Optimization-based?
  - Optimization-based approaches need accurate models
  - Difficulties in determining accurate models for complex networks (multi-hop)(*)
  - Machine learning addresses this by learning hidden characteristics of any network
- Why go deep?
- Why reinforcement learning?

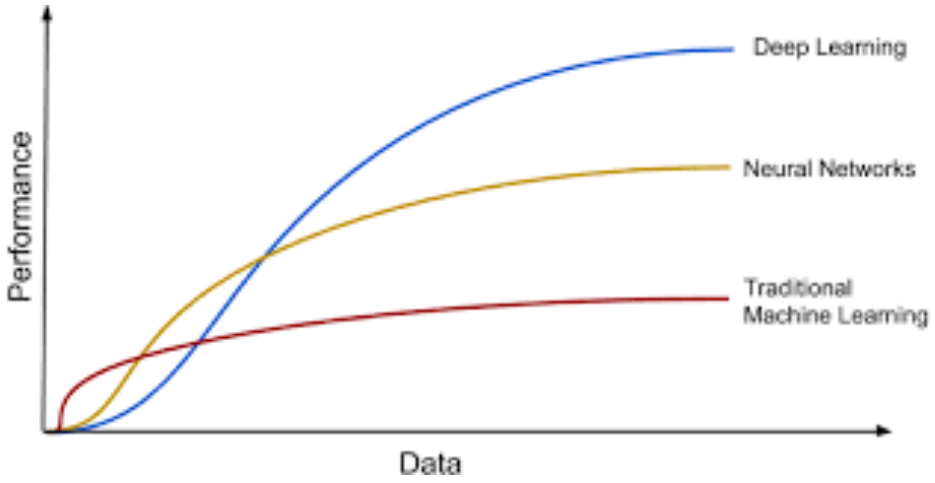
(*) Z. Xu *et al*., "Experience-driven Networking: A Deep Reinforcement Learning based Approach," *IEEE INFOCOM 2018 - IEEE Conference on Computer Communications*, Honolulu, HI, 2018, pp. 1871-1879.

Deep Learning Approach

– Machine Learning or Optimization-based?

– **Why go deep?**

Data dependency

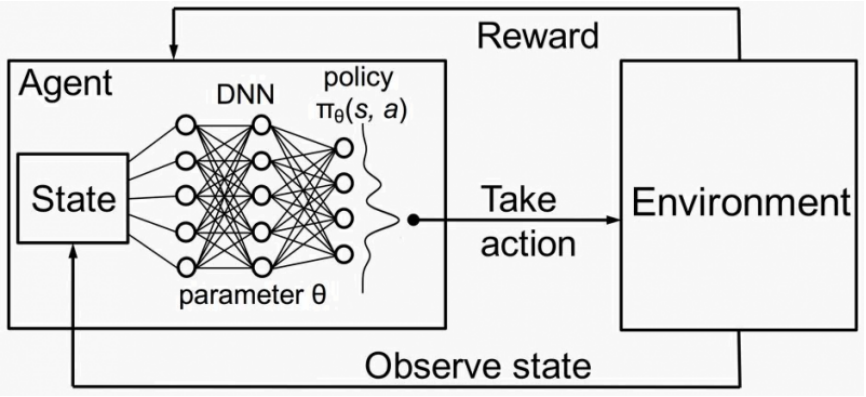


https://www.sumologic.com/blog/machine-learning-deep-learning/

– Why reinforcement learning?

Deep Learning Approach

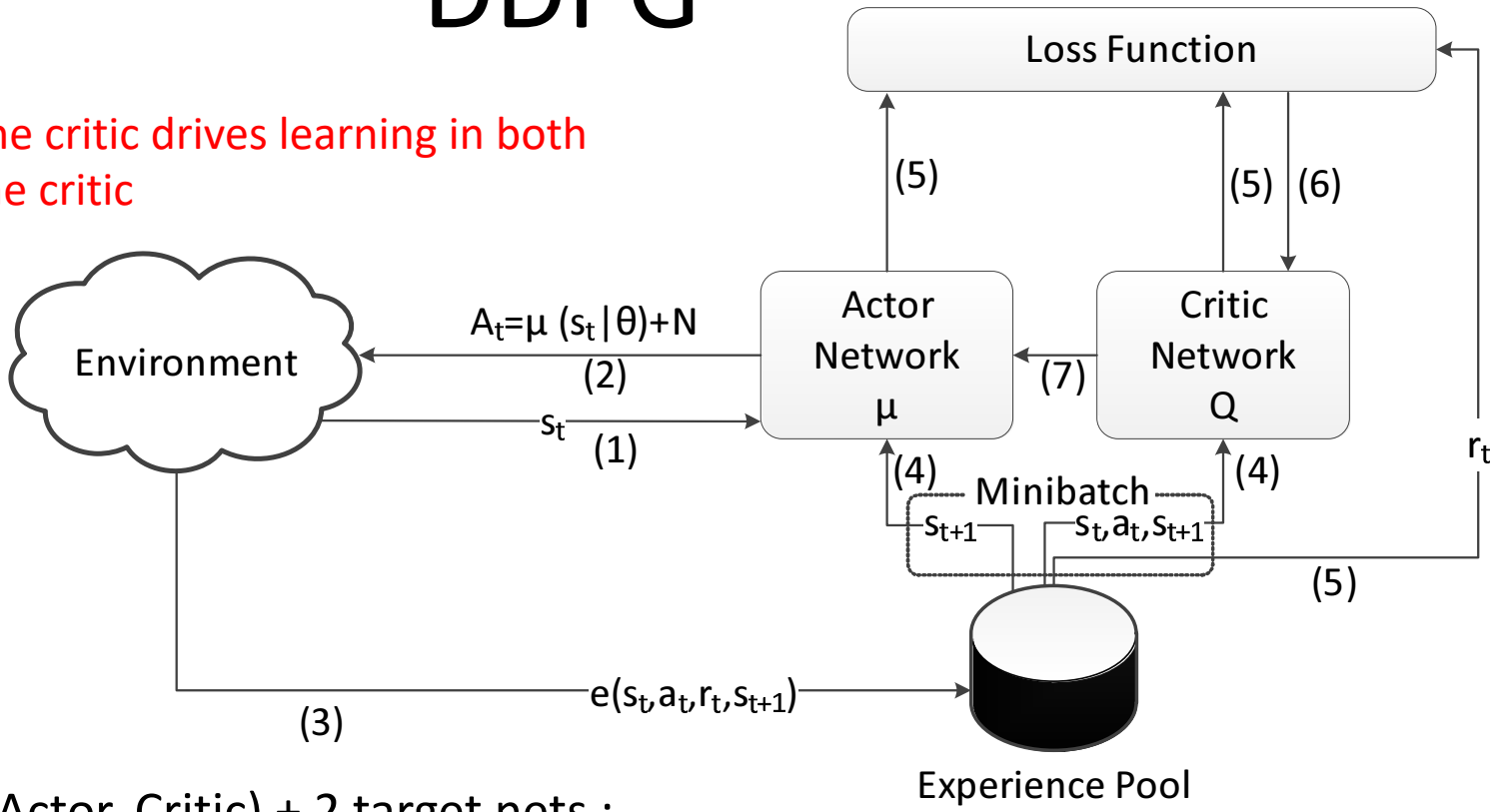
- Machine Learning or Optimization-based?
- Why go deep?
- **Why reinforcement learning?**
  - Its good performance and capability have been confirmed (*)



(*): Asaf Valadarsky et al., "A Machine Learning Approach to Routing", CoRR, 2017

DDPG[1]

The output of the critic drives learning in both the actor and the critic



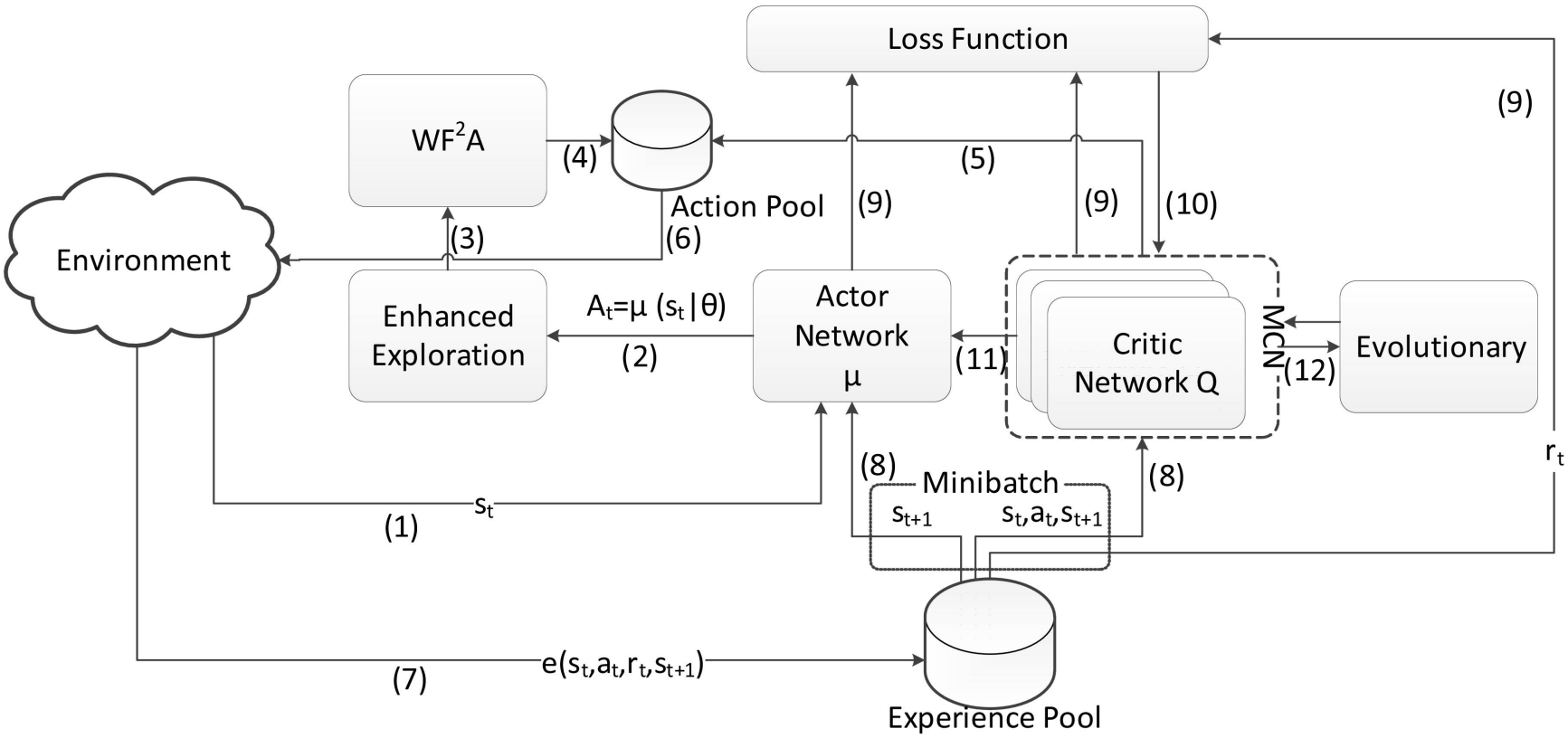
2 neural nets (Actor, Critic) + 2 target nets :

- Critic network learns Value function
  - Based on state + action
- Actor network learns the Policy

1 T. P. Lillicrap, J. J. Hunt, A. Pritzel, N. Heess, T. Erez, Y. Tassa, D. Silver, and D. Wierstra, "Continuous control with deep reinforcement learning," CoRR, vol. abs/1509.02971, 2015 (last updated on Jul. 2019) – Google DeepMind

DRL Agent

Based on DDPG



WF²A: Weighted First Fit Algorithm – WF2A

DRL Agent

- Weighted First Fit Algorithm (WF^2A)(*)

For VNF embedding:

•Step 1: Sort substrate nodes in terms of their weights

•Step 2: Attempt deploying VNF at the lowest weight substrate node

•If the substrate node can host the VNF

  •Step 3a: Update remaining resources of the substrate node

•If the substrate node cannot host the VNF:

  •Step 3b: Remove that node from the selection process and back to step 2

For VL embedding:

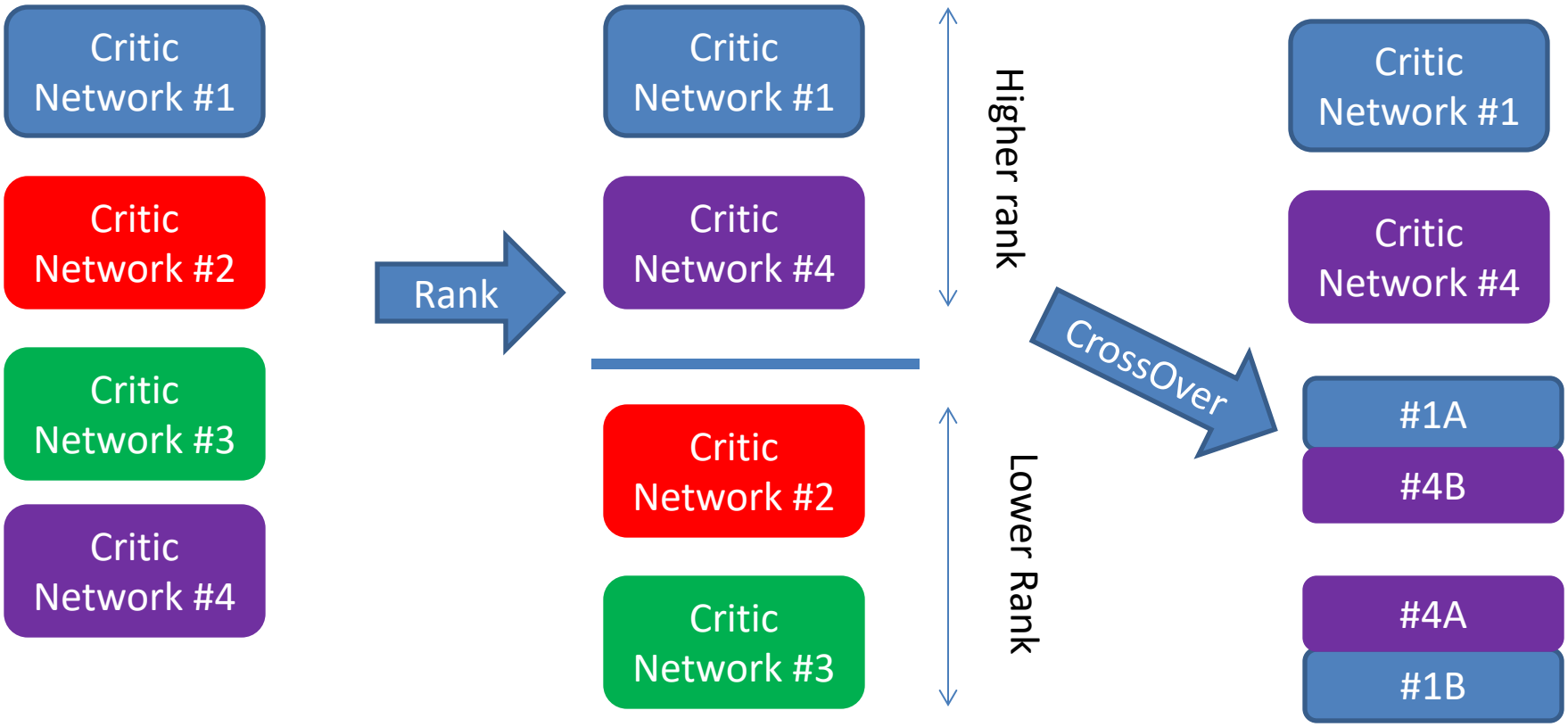
Use Dijkstra algorithm to identify the lowest cost path to connect VNFs

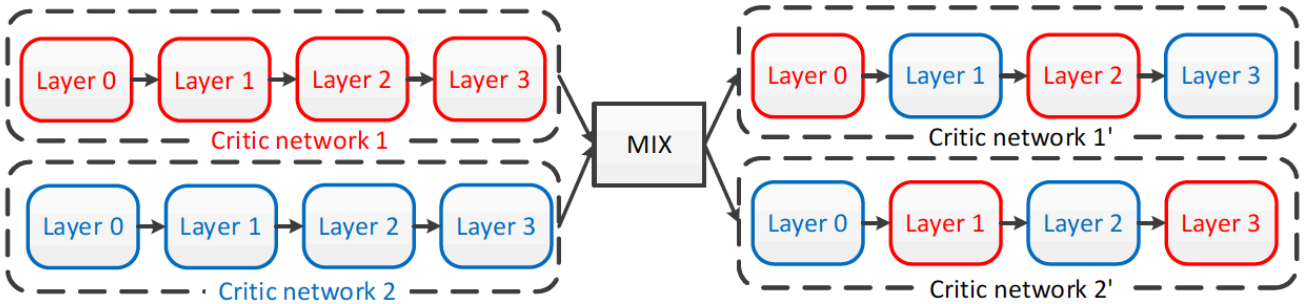
→ Final allocation decision

(*) This algorithm has been introduced in

P. T. A. Quang, Y. Hadjadj-Aoul and A. Outtagarts, "A Deep Reinforcement Learning Approach for VNF Forwarding Graph Embedding," in *IEEE Transactions on Network and Service Management*, vol. 16, no. 4, pp. 1318-1331, Dec. 2019. doi: 10.1109/TNSM.2019.2947905

Evolutionary Actor-Multi-Critic Model





Environment

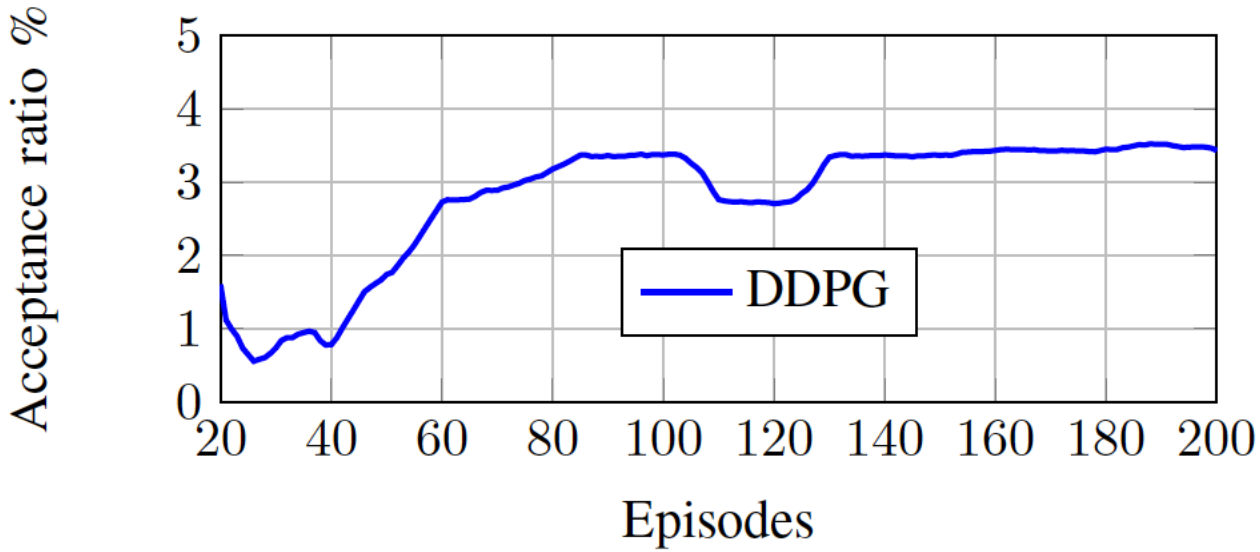
Two versions

- Simulated environment
  - Python, Tensorflow, Keras
  - OMNET++
  - REST interfaces

- Emulated environment
  - Python, Tensorflow, Keras
  - MININET (ContainedNet - Docker)
  - Orchestrator + SDN
  - REST interfaces

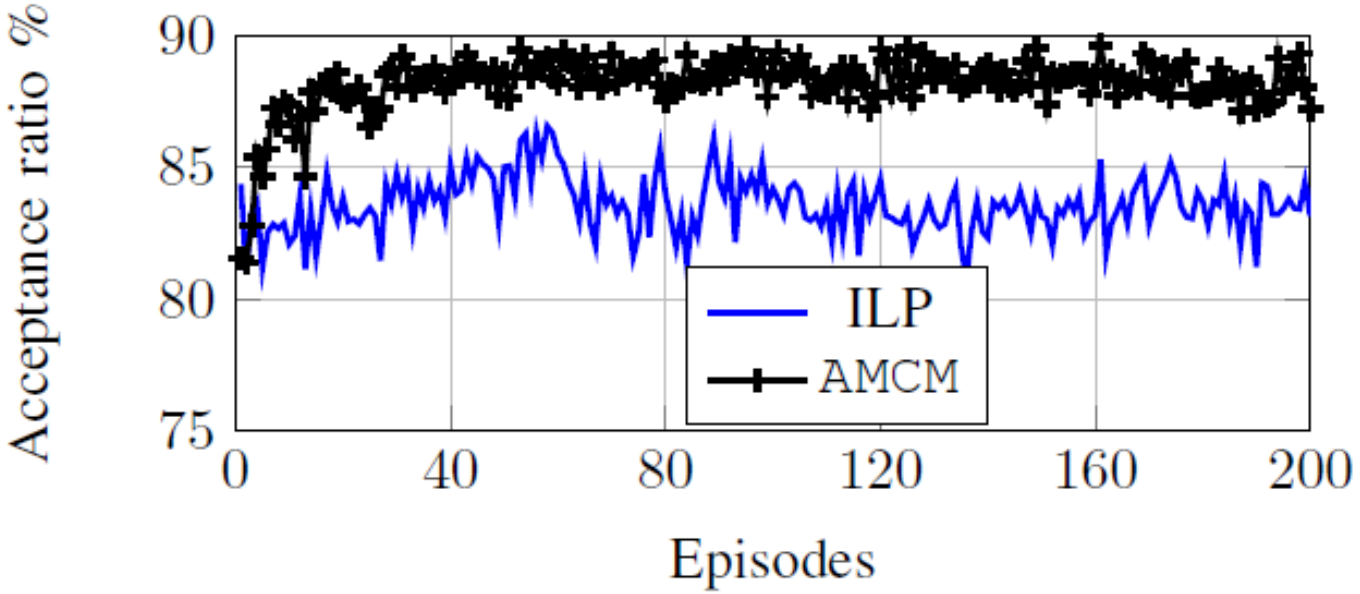
Results

- Placement with DDPG



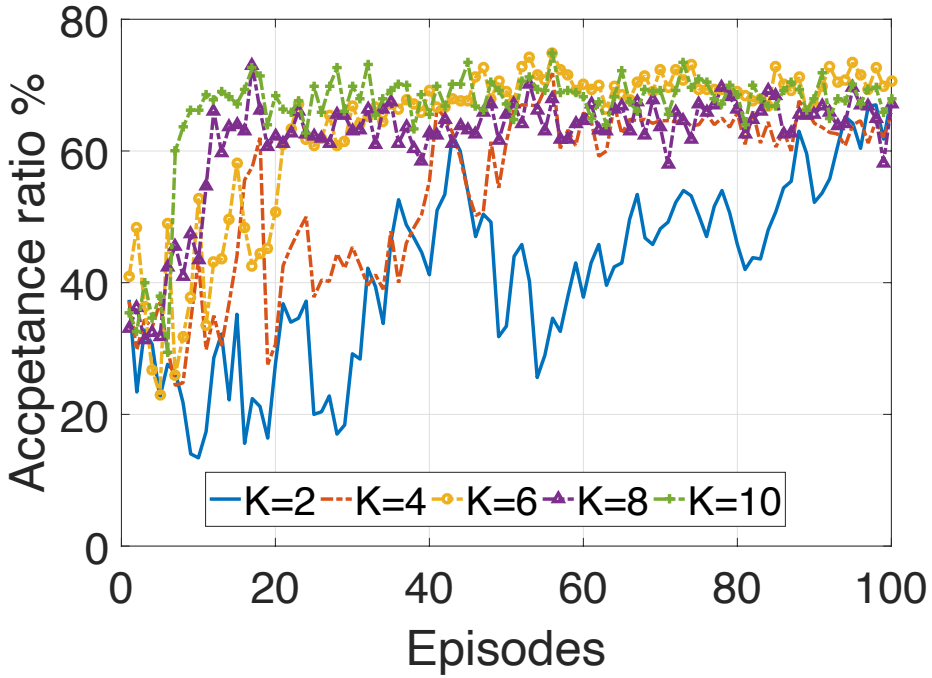
ILP vs AMCM

ILP: Integer Linear Programming based solution
AMCM: Actor-Multi-Critic Model (*)

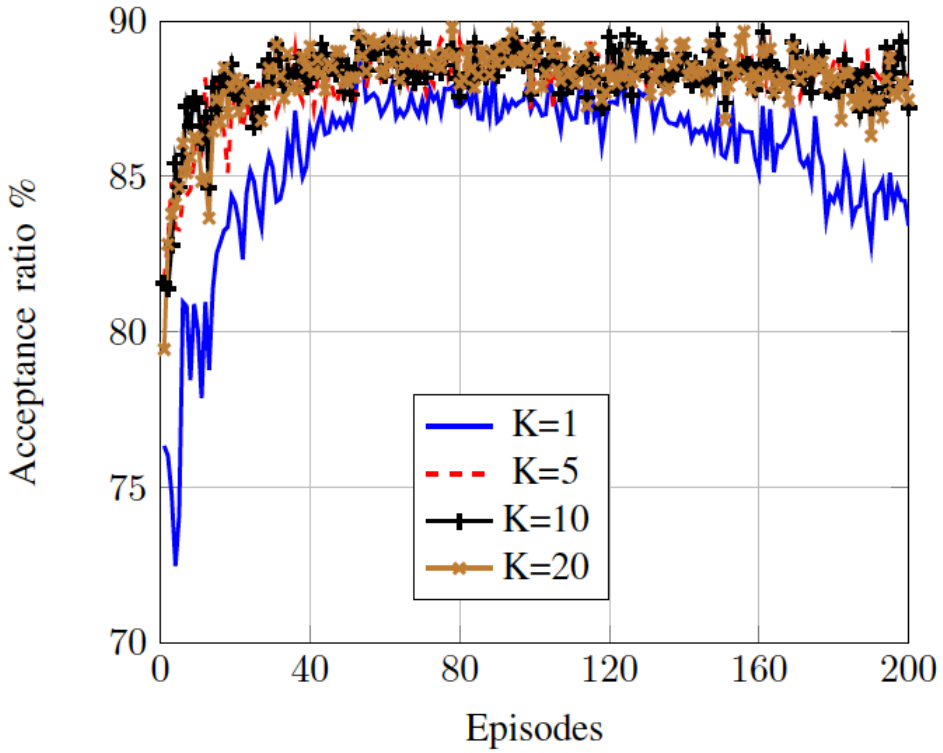


(*)P. T. A. Quang, Y. Hadjadj-Aoul and A. Outtagarts, "A Deep Reinforcement Learning Approach for VNF Forwarding Graph Embedding," in *IEEE Transactions on Network and Service Management*, vol. 16, no. 4, pp. 1318-1331, Dec. 2019. doi: 10.1109/TNSM.2019.2947905

Impact of the number of fully connected Layers

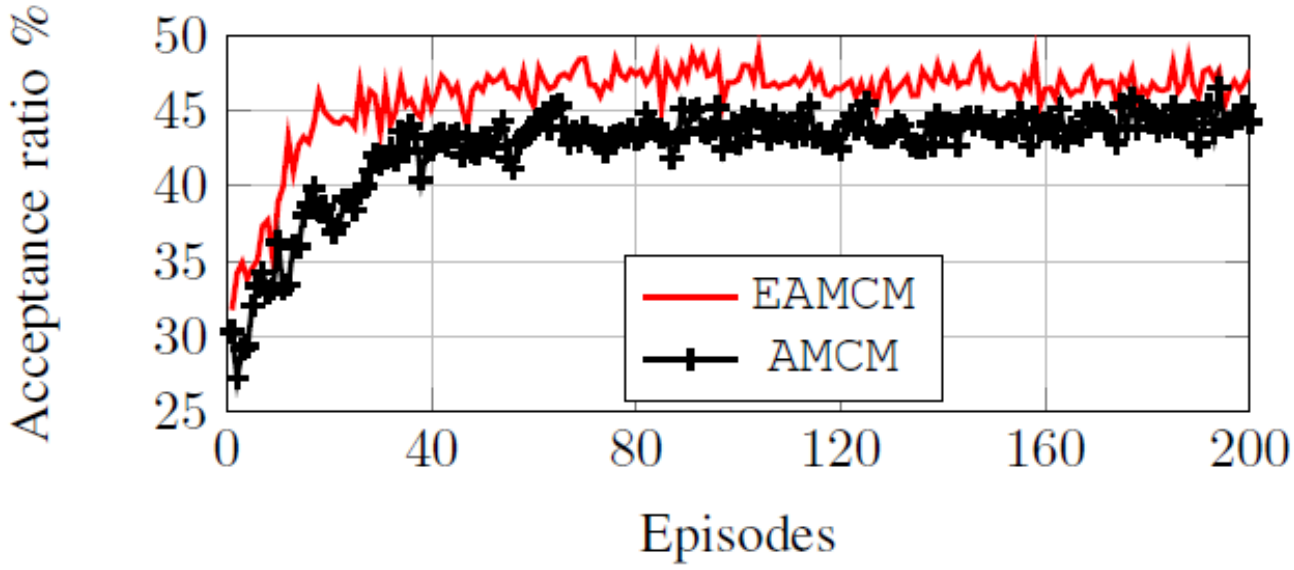


Impact of the number of critic nets



AMCM vs EAMCM

More congested system …



Conclusions

- Adopt Enhanced Exploration framework to boost the performance of DDPG
- Proposed an evolutionary algorithm to improve the learning process of critic networks
- The simulation confirms that the evolutionary algorithm can improve the performance remarkably

Thanks for your attention